before we reach the Mississippi River the ratio is reduced to 1·32.

In Great Britain the amount of rain with a falling is twice that with a rising barometer, but, advancing eastward, this ratio rapidly diminishes, and in Central Europe the precipitation is greater when the barometer is rising than when it is falling. Plates are appended, which exemplify in an emphatic manner all the facts that have been tabulated concerning rainfall. Five gradations of colour only have been used to indicate the rainfall of less than 10 inches to over 75 inches. By this means the main results have been rendered more prominent.

R. A. GREGORY.

THE SOURCES OF THE NITROGEN OF VEGETATION.[1]

NO problem relating to the nutrition of plants has given rise to so much discussion as that of the source of their nitrogen and the methods of its assimilation. It is obviously both a matter of the highest scientific interest, and also, owing to the high price of combined nitrogen in manures and the comparative ease with which it is washed out of the soil in the form of nitrates, one of great practical importance to the agriculturist and the community.

Ever since the discovery of the composition of atmospheric air by Priestley, Scheele, and Lavoisier, the question as to whether plants were able to absorb and utilize free nitrogen has attracted much attention. At the end of the last century, or beginning of this, Ingenhousz, Sennebier, Woodhouse, and De Saussure became interested in the subject.

Boussingault commenced his experiments in 1837; Ville, whose results conflicted with those of Boussingault, in 1849; and, shortly after, this last named investigator started a new series of experiments which confirmed his former conclusions that plants, under the conditions of the experiment, were not able to assimilate free nitrogen.

In 1857, experiments on the assimilation of free nitrogen by plants were started at Rothamsted; and in 1861 was published, in the Philosophical Transactions, the classical memoir of Lawes, Gilbert, and Pugh, on this subject.

In this earlier paper a brief history and summary of the results of other experimenters is given, and then the recent results obtained at Rothamsted. The conclusions arrived at were identical with those of Boussingault, that there is no evidence that plants assimilate nitrogen. Still the authors allowed that there were some difficulties with regard to the supply of nitrogen to leguminous plants, which assimilate from some source or another much more nitrogen than gramineous plants under similar conditions of supply of combined nitrogen.

It was admitted that, "if it be established that the processes of vegetation do not bring free nitrogen into combination, it still remains not very obvious to what actions a large proportion of the existing combined nitrogen may be attributed."

These views, that plants were unable to assimilate free nitrogen were widely and generally held for many years, though there have always been some dissentients.

In the meantime, however, the indefatigable investigators of Rothamsted have not been resting in the matter, but have added much to our exact knowledge of the supplies of combined nitrogen to the soil from the air, on the amount and nature of the combined nitrogen in soils and in crops, on the processes of nitrification in soils, and the amount of nitrogen removed from soils in crops and in drainage.

During the last few years the main question as to the availability of atmospheric nitrogen to plants has taken a somewhat different aspect: it is now often suggested that though the higher plants are unable to directly take up free nitrogen, yet indirectly it is brought under contribution in some way; the ways most generally favoured being either under the influence of electricity of low tension, or of microbes or some low forms of organisms; and by such means it is thought that nitrogen is brought into a form in which it is useful to the higher plants.

In Sir J. B. Lawes and Dr. Gilbert's new memoir they give a summary of some previously published Rothamsted results, chiefly relating to nitric acid in soils and subsoils; also of the results of Cameron, S. W. Johnson, Hampe, Wagner, and Wolff, on the assimilation of nitrogen by plants, from more or less complex organic bodies like urea, uric acid, hippuric acid, and tyrosine.

A number of new determinations of nitric acid in soils and subsoils, and of total combined nitrogen in the surface soils of the Rothamsted experimental plots are given; and also the results of numerous experiments with dilute solutions of organic acids on soils, to ascertain the action of such dilute acids, in some degree comparable to the acid sap of the roots of plants, on the organic nitrogenous matter of soils.

In the second part of the memoir are summarized the recent results and conclusions of other workers relating to the fixation of free nitrogen.

Probably the results of Berthelot, which have from time to time been published in the *Comptes rendus*, have influenced the opinions and the course of inquiry in recent years more than any others. In 1876 and 1877, Berthelot found that various organic compounds under the influence of the silent electric discharge, even of low tension, were able to fix free nitrogen, and concluded that such fixation of nitrogen takes place in ordinary soils under normal conditions. In 1885 he published results showing the fixing of free nitrogen by certain soils under conditions which led him to believe that the action must be due to the influence of micro-organisms, and to such action M. Berthelot seems now inclined to impute most influence in the matter. Although the gains in nitrogen, expressed in percentages, were very small, yet there was gain in all cases when the soils were exposed either in the open, or in a room, or in closed flasks, and no gain when the soils were sterilized. Unless there be some unrecognized source of error, such as might easily be imagined in the case of the freely exposed soils, one seems bound to accept Berthelot's conclusions. Dehérain's results at Grignon are next discussed; they are chiefly on the gains or losses occurring on experimental field plots, and are perhaps not of such a nature as to materially assist one at the present stage of the inquiry.

Joulie's results, as given in the *Bulletin de la Société des Agriculteurs de France* in 1886, showed exceedingly large gains of nitrogen, which he is inclined to ascribe to the action of microbes; here the gains of nitrogen were certainly more than take place in ordinary farm practice, and occurred with buckwheat, which is not usually considered as a "nitrogen collector."

Dietzell's experiments are mentioned; in all cases but one, in which there was a slight gain in nitrogen, the results are fully accordant with established facts. B. Frank, who has recently written a paper on the whole aspect of the question, has published some experiments of his own. He concluded, as have others, that two opposite actions are at work in the soil—one setting nitrogen free, and the other bringing it into combination, the latter being favoured by vegetation—but that there is no decisive evidence to show how this combination is brought about; it does not necessarily follow that the plant itself effects the combination. Some of Frank's experimental conditions, however, were considerably removed from those occurring in the ordinary course of farm practice.

The very important and most interesting experiments of Hellriegel and Wilfarth follow. The first of these were described at the Berlin meeting of the *Naturforscher-Versammlung*, in 1886; subsequent experiments were described at the Wiesbaden meeting in 1887, and they were further given in a paper by König, published in Berlin in 1887; but the full text and details of their work were not published in time for Messrs. Lawes and Gilbert to refer to. A paper on these results appeared last November in *Beilageheft zu der Zeitschrift des Vereins für die Rübenzucker-Industrie*, and the work of these investigators is described by M. Vesque in the January number of *Annales Agronomiques*.

The experiments date from 1883 onwards, and were on cereals, buckwheat, rape, and various leguminous plants. The plants were grown in pots in washed siliceous sand, to which the necessary cinereal constituents were added. In this all the plants grew normally until the nitrogen in the seed was used up; then the plants not belonging to the Leguminosæ ceased growing until supplied with some combined nitrogen, nitrate of soda was used, when growth was proceeded with almost exactly in proportion to the amount of nitrogen supplied. With the Leguminosæ the results were more eccentric: sometimes the plants died of nitrogen-hunger; sometimes after a time of such hunger they recovered and produced abundant growth. To the sterile soil with the young plants there was added in a large number of cases a small quantity of an extract of a garden soil; the extract used contained less than one milligramme of nitrogen; the oats, rape, and buckwheat remained undeveloped, but the leguminous plants soon became deep green and grew vigorously. If the soil extract were previously sterilized by heat, it produced no effect. Moreover the soil used in the preparation of the extract was of importance; with peas any soil extract answered, but not so with lupins and sainfoin; with these plants, to render success certain it was found necessary to use an extract of a soil which had previously grown the same plants. Some experiments were also made in large sealed flasks, to which carbon dioxide was admitted at intervals; in these the results were practically the same as in free air, showing that it was not the combined nitrogen of the air which was absorbed.

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[1] "On the Present Position of the Question of the Sources of the Nitrogen of Vegetation, with some New Results, and Preliminary Notice of New Lines of Investigation." By Sir J. B. Lawes and Prof. J. H. Gilbert. Phil. Trans. 1889, clxxx. B. pp. 1–107.

It was also found that whilst on the leguminous plants which developed well, either with or without the addition of soil extract, the characteristic tubercules of papilionaceous plants were well marked, on those which did not develop in the sterile soil, and also on plants grown in sterilized soil to which nitrate had been added, and which plants developed at the expense of the added nitrogen, but did not assimilate free nitrogen, there were no tubercules. Hence there is obviously some connection between the production of the tubercules and the assimilation of the free nitrogen. In all cases where free nitrogen is presumably assimilated by the plant, the soil is also enriched in nitrogen, the more so when the plant growth is more vigorous, and this excess of nitrogen in the soil is almost entirely in organic combination.

The general conclusions are that leguminous plants, though they are able to make use of combined nitrogen in similar forms to those the graminaceous plants utilize, yet differ from this latter order of plants in being able to use some other form of nitrogen, not that existing in the soil. This second source of nitrogen must be the free nitrogen of the air, which the Leguminosæ utilize through the agency of certain micro-organisms which are in symbiosis with them, and exist in the tubercules of the roots of this order of plants.

The results obtained by von Wolff at Hohenheim, from 1883 onwards, are mentioned. Wolff is not inclined to admit that plants assimilate free nitrogen, but thinks that the only remaining hypothesis is that certain plants can appropriate the combined nitrogen of the air, either directly through their leaves or more probably after absorption by the soil. A porous soil probably absorbs far more nitrogenous compounds from the air than an equal superficial area of dilute acid, as used in experiments by Schlœsing, Kellner, and Müller. He admits, however, that it is difficult to see why the grasses are unable to benefit by this equally with the legumes.

W. O. Atwater has published three papers on various aspects of the subject in the *American Chemical Journal*. In these papers he gives results of his own experiments and also discusses those of others. He concludes that in many of his experiments with peas, when the growth was normal, half or more of the total nitrogen of the developed plants was obtained from the air. In what way the nitrogen was acquired, the experiments do not show, but Atwater inclines to the idea that the plants themselves directly acquired the atmospheric nitrogen. The conclusion of this second part of the memoir gives some recent experiments and opinions of Boussingault on the subject. He remained strongly of the opinion that plants were unable to assimilate free nitrogen; although, as is here pointed out, some of his experiments in 1858 and 1859, with lupins, might be considered as leading to such a conclusion.

The third part of the memoir gives a summary and general considerations and conclusions.

Regarding the evidence relating to other sources than free nitrogen, Lawes and Gilbert have shown that the amount of nitric acid remaining in a soil is much less after the growth of a crop than under corresponding conditions without a crop. Also that nitrification in soils is more active where leguminous crops are grown than where gramineous plants only are present; and that deep-rooted leguminous plants like *Medicago sativa* or *Melilotus leucantha* take up more nitric acid from the soil than shallower-rooted leguminous plants like *Trifolium repens*. But the supply of nitric acid in some soils, such as clover-exhausted land or bean-exhausted land, is inadequate to account for the nitrogen taken up by other leguminous crops grown on such land. No very definite conclusions could be drawn from the Rothamsted experiments as to the power of the acid sap of roots to take up nitrogenous organic matter from the soil, though it is seen to be not improbable that green-leaved plants can "take up directly, and utilize, amide bodies rendered soluble within the soil by the action of their acid root sap."

Our authors in conclusion point out that, since experimenting in free air instead of in closed vessels, as in Boussingault's and their own researches, has become common, there has been a great accumulation of evidence tending to indicate the fixation of free nitrogen. The modes of explanation of the gain of nitrogen are: that it has been absorbed from the air, either by the soil or by the plant; that there is fixation of free nitrogen within the soil by the agency of porous and alkaline bodies; that there is fixation in the soil by the agency of electricity; that there is fixation by the plant itself; that there is fixation under the influence of micro-organisms within the soil. The balance of recorded evidence is undoubtedly in favour of the last-mentioned mode of explanation. "Indeed, it seems to us," say Lawes and Gilbert, "that, if there be not experimental error, there is fixation of nitrogen within the soil, under the influence of micro-organisms, or other low forms of life." But they think that final judgment must be held in abeyance for the present. Most of their own and Boussingault's previous experiments excluded, by their conditions, the action of electricity or of micro-organisms.

They then consider some of the facts of agricultural production in their bearing on the question as to how far the establishment of the reality of the fixation of free nitrogen is necessary to the solution of problems of agricultural production. They point out that the loss of nitrogen in ordinary farm practice is not so great as Berthelot and others have assumed; the annual loss of nitrogen by cropping in Great Britain, for example, is probably under 20 pounds per acre. The loss by drainage may in some cases be considerable, and in special cases there may be loss by evolution of free nitrogen. Probably the loss of free nitrogen from the plant itself during growth, which is assumed by some, does not occur. The accumulation of combined nitrogen which occurs in the surface soil of pastures is not conclusively explained, but it may have a subsoil origin, and this assumption has as much evidence in its favour as that it has an atmospheric origin. In the soil and subsoil of Rothamsted, to a depth reached by the deeper-rooting plants, there is 20,000 pounds of combined nitrogen per acre; in very many of the soils of this country there is more, though in some less than this: the accumulation of nitrogen in the surface soil may well be due to nitrogenous crop-residue, the nitrogen of which comes principally from the subsoil. Again the natural fertility of most soils is without doubt due to the accumulation of ages of natural vegetation with little or no removal; and the amount of nitrogen even now brought into combination under the influence of electricity, over a given area, would be sufficient, with growth and little or no removal, to account for the accumulations in natural prairie or forest lands even of the richest.

The Rothamsted experiments have shown that after growing crops for many years without nitrogenous manures there has always been a diminution of nitrogen in the top soil; this has been found to be the case with diverse crops, including gramineous, cruciferous, chenopodiaceous, and also leguminous crops, and with a four-course rotation of crops. There has not been compensation of nitrogen from the air, or at all events to the extent of the annual losses. "The agricultural production of the present age is, in fact, as far as its nitrogen is concerned, mainly dependent on previous accumulations; and as in the case of the use of coal for fuel there is not coincident and corresponding restoration, so in that of the use or waste of the combined nitrogen of the soil, there is not evidence of the coincident and corresponding restoration of nitrogen from the free to the combined state."

It is not yet conclusively proved that the whole of the nitrogen of leguminous plants comes from the subsoil; it is equally not proved that it comes from the air; though in the case of crops belonging to other natural orders it may be affirmed that atmospheric nitrogen is not the source. May it be that the development of organisms capable of bringing free nitrogen into combination within the soil is favoured by leguminous growth and crop-residue, as there can be little doubt is the case with the organisms which produce nitrification?

Frank has shown that on the roots of certain trees, especially the Cupuliferæ but also on willows and some Coniferæ, is a fungus-mantle which is believed to be in true symbiosis with the higher plant; and it may well be supposed that the fungus partly assists the tree by bringing the organic nitrogen of the soil into a form in which it becomes available to the chlorophyllaceous plant; much in the same way as has been observed by Gilbert in the case of fairy-rings, where the fungus, so to speak, prepares the nitrogenous nutriment for the grass. That the tubercules that are nearly always present on the roots of leguminous plants are in some way connected with the assimilation of nitrogen by the plants is an hypothesis that is gaining ground. Much study has of late years been devoted to the morphology and functions of these tubercules by, amongst others, Tschirch, Brunchorst, Frank, Van Tieghem, Lundström, and Marshall Ward; and still more recently by Bréal, Beyerinck, and Prazmowski. It seems almost certain that these tubercules contain micro-organisms, which are the proximate cause of the excrescences, and these may live in symbiosis with the legumes, and prepare their nitrogenous food possibly from free nitrogen. The tubercules are richer in nitrogen than the roots themselves, and some observers look upon them as being merely reservoirs of nitrogenous nutriment, not as manufactories. Beyerinck (*Botan. Zeitung*, 1888) has obtained and cultivated an organism which he calls *Bacillus radicicola*, from these tubercules, and studied some of its reactions. It seems very probable that further study of these tubercules of the Leguminosæ may put us on the right track for solving the mysteries of the nitrogenous nutrition of this order of plants.

In a postscript to the memoir the authors state that they have started some experiments with leguminous plants much on the same lines as those of Hellriegel and Wilfarth. The results of these experiments will be looked forward to with very great interest.

This memoir is a most welcome and solid contribution to a most important problem.' It is quite obvious that the last word on the subject has not been said, and probably very much more work must be done before it is. The authors, from their own labours and thought on the subject, continued through so many years, are well able to criticize the work of others, and this they have here done, as far as most of the important papers published up to date are concerned, in an able and frank manner. If leguminous plants are able to avail themselves of the free nitrogen of the air, or if soils are able, through the agency of microbes or in other ways, to fix free nitrogen, the exact conditions necessary for the accomplishment of these ends is not yet known. The conditions of risk and exposure to accidental sources of nitrogen-gain in small experiments in the open air are very great, and experiments made under such conditions require very careful verification. Also the methods of nitrogen determination used should be subjected to rigorous investigation and control, as also the methods of taking the samples used in analysis, which in the case of a complicated body like a soil presents great difficulty in obtaining a perfectly homogeneous mixture. The exact limits of experimental error in the various determinations want investigation. The subject, from its important practical bearings, is worthy the attention of a scientific commission who could give undistracted attention to it. E. K.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

OXFORD.—An examination will be held at Queen's College, in the first week of October, to fill up at least two open Classical Scholarships for candidates proposing to commence residence this October, and one open Scholarship in Natural Science (Chemistry and Physics) for candidates proposing to commence residence in October 1890.

Classical candidates must not have exceeded nineteen years, and Natural Science candidates eighteen years, on October 10, 1889.

A further notice will be issued.

SCIENTIFIC SERIALS.

American Journal of Mathematics, vol. xi. No. 4 (Baltimore, July 1889).—Prof. Cayley opens the number with a resumption of his memoir on the surfaces with plane or spherical curves of curvature (pp. 293-306).—The circular cubic with double focus on itself is treated by Schröter and Durège (*Crelle*, Bd. v.). Mr. F. Morley, writing on the geometry of a nodal circular cubic (pp. 307-16), gives a geometrical account, illustrated by figures, of the case when the curve, in addition, is nodal. Some properties of the special case when the inflexion is at infinity are given by Dr. Booth (*Quarterly Journal*, vol. iii.) in his discussion of the logocyclic curve (cf. vol. i. of his "Collected Papers," cap. xxx.).—The next paper supplies a defect in MM. Briot and Bouquet's "Propriétés des fonctions définies par des équations différentielles" (*Journ. de l'École Pol.*, cap. xxxvi.): it is entitled, "On the Functions defined by Differential Equations, with an extension of the Puiseux polygon construction (see *Journ. de Math. pures et appliquées*, i. 15) to these equations" (pp. 317–28), and is written by Mr. H. B. Fine.—In the memoir "Sur les solutions singulières des équations différentielles simultanées" (pp. 329-72), M. Goursat extends results obtained by M. Darboux to simultaneous differential equations and to equations of higher order.—The number, and volume, concludes with a note by J. C. Fields, on the expression of any differential coefficient of a function of any number of variables by aid of the corresponding differential coefficients of any n powers of the function, where n is the order of the differential coefficient (pp. 388–96).—All these papers are, of course, purely mathematical: there is a physical paper (pp. 373–87) by Prof. H. A. Rowland, entitled "Electro magnetic Waves and Oscillations at the Surface of Conductors." The calculations are founded on Maxwell's equations. "In these equations occur two quantities, J and ψ. Maxwell has given the reasons for rejecting ψ, and has shown that neither J nor ψ enter into the theory of waves. In order, however, that there shall be no propagation of free electricity in a non-conductor, the components of the electric force must satisfy the equation of continuity, and this leads to components of the vector potential satisfying the same equation, and $J = 0$ therefore. I have satisfied myself that there is absolutely no loss of generality from these changes."

IN the *Nuovo Giornale Botanico Italiano* for July, Sig. A. Bottini has an interesting article on the structure of the olive, especially on that of the several layers of tissue of which the ripe fruit is composed. A disease to which the crop has been recently liable he believes to have been erroneously attributed to a parasitic fungus, *Septoria oleaginea*.—The greater part of this number is occupied by the proceedings of the meeting of the Botanical Society of Italy held in Florence.—Prof. Arcangeli gives an account of a series of experiments on the amount of heat due to the respiration of fungi. The greatest elevation of temperature he finds to amount to 1°·25 C. in the case of *Lepiota excoriata*. In all cases the elevation of temperature is most conspicuous about midday, or early in the afternoon.—The colouring-matter of the cones of *Abies excelsa* is stated by Sig. L. Macchiati to be due to a mixture of three distinct substances, two of them crystallizable, accompanied by a waxy substance.

Das Wetter for July contains:—(1) The second part of an explanatory discussion, by Dr. Wagner, of the recently published instructions for the observers of the Prussian Meteorological Institute. The points referred to relate especially to rainfall and thunderstorm observations. The author refers to the variability of rainfall values both as regards time and place, and to the necessity of stations near each other, to explain the irregularities of the yearly amounts. It is only since 1887 that such a system has been established in North Germany, where it is proposed to raise the number of stations to 2000, which will then only give one for about 77 square miles. The hours of observation are also discussed, the result being that the usual morning observation cannot be altered; but the instructions direct that the rainfall should be set down to the day upon which it is observed; this has generally been done in Prussia, whereas in other countries it is put down to the previous day. The author refers to the importance of the measurement of rain during the passage of thunderstorms, and also to the advantage to be derived from the more general use, at stations of the second and third order, of simple registering barometers and thermometers, similar to those of Richard Frères.—(2) A criticism of Herr Falb's weather predictions taken from an article in the *Göttingen Zeitung*. M. Falb bases his theory on the influence of the sun and moon upon the interior of the earth, and upon the surrounding media of air and water, and calculates certain "critical days" from the relative positions of these bodies. The author of the article has checked the predictions sent to the German agricultural Press since April 12, and points out that although the weather of May has been unusually warm, no mention of the fact was contained in the predictions, and concludes with the remark that a theory which shows such little success, as in the comparison in question, is useless to the agriculturist.—(3) A description, by Dr. Wagner, of the new popular Observatory, "Urania," opened on July 3, in Berlin, on the site of the Exhibition buildings. It contains a large equatorial, over 16 feet in length, with a lens of about 12½ inches in diameter, a large number of instruments and microscopes, and a spacious lecture theatre.